DYNAMIC MODULUS MASTER CURVE AND CHARACTERIZATION OF SUPERPAVE HMA CONTAINING VARIOUS POLYMER TYPES

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ABSTRACT

The Superpave technology has been implemented by the Ministry of Transport (MOT) to design Hot Mix Asphalt (HMA) across the Kingdom of Saudi Arabia (KSA). The Simple Performance Test (SPT) measures accurately and reliably the mixture parameters that are highly correlated to pavement performance over a diverse range of traffic and climatic conditions. The top SPT candidate is the dynamic modulus test. The Saudi Arabia MOT approved list for asphalt binder modifiers includes Styrene-Butadiene-Styrene (SBS), Sasobit (Saso), and Crumb Rubber Modifier (CRM). This study was aimed to characterize the performance of the HMA containing those modifiers. Superpave HMA mixtures containing PG64-10 and PG70-10 at variable air contents were examined. The Performance Grade PG70-10 was obtained by blending virgin bitumen (PG64-10) with SBS, Saso, and CRM. Binders were characterized using the Brookfield Rotational Viscometer (BRV), Dynamic Shear Rheometer (DSR), and Bending Beam Rheometer (BBR). Superpave HMA mixtures were tested for volumetric and dynamic characteristics. The SPT testing conditions were selected to simulate those for Hail Region in the KSA, in terms of climatic and traffic data.

Dynamic Modulus test was conducted at variable temperatures and load frequencies. Master curves were developed at various reference temperatures simulating those for Hail Region. Dynamic modulus results were statistically examined to investigate polymer type and testing conditions impacts on HMA performance. Recommendations for polymer type and the incorporation of the SPT during the Superpave HMA design and characterization are presented.

1. INTRODUCTION

The Superpave mix design method is a product of the Strategic Highway Research Program (SHRP). The SPT is a test method(s) that accurately and reliably measures a mixture response characteristic or parameter that is highly correlated to the occurrence of pavement distress over a diverse range of traffic and climatic conditions. The major SPT output is the dynamic modulus, also known as the E*, that identify the stiffness value for the asphalt pavement mixture. The dynamic modulus is the material property that relates stress to strain for a linear viscoelastic material.

The SPT conducts the following three tests; Dynamic Modulus; Flow Number, and Flow Time. The top SPT candidate is the dynamic modulus test. It was found that this test appears to have the potential to tie the Superpave volumetric mix design directly to field performance. It was also found that the dynamic modulus test has the potential to be a unique SPT test which could predict rutting, fatigue cracking, and thermal cracking in asphalt concrete pavements (Witczak et al., 2002). In the National Corporative Highway Research Program (NCHRP) Project 9-19, high temperature dynamic modulus test data showed excellent correlation with rutting in field pavements, and intermediate temperature dynamic modulus test data showed fair correlation with fatigue cracking. Additional advantage of this test is that it is nondestructive; a single specimen could be tested at multiple temperatures and multiple load frequencies. In the SPT test a continuous haversine axial compressive load is applied to a specimen at a given temperature and loading rate. Measured stresses and strains are then used to calculate the resulting dynamic modulus and phase angle (Bonaquist et al., 2003). For the development of master curves for HMA characterization and pavement design, tests are

conducted at temperatures of -10, 9, 21.1, 37.8 and 54.4 °C using loading frequencies of 25, 10, 5, 1.0, 0.5, and 0.1 Hz. The resulting modulus measurements are then shifted using time-temperature superposition to obtain a master curve. The modulus master curve is mathematically modeled by a sigmoidal function.

In the current study, dynamic modulus test was conducted at variable temperatures and load frequencies to develop master curves for the standard MOT asphalt mixture for base course (25R8A4Y) involving different polymer types. Mixture results were analyzed to investigate the incorporation of the SPT testing during the Superpave HMA design across the KSA.

2. MATERIALS USED

Aggregates were obtained from Al-Harbi Trading & Contracting Co. Ltd paving project at Hail Region (Hail-Al Gouf project). This project involved the construction of 6-lanes divided highway between Al Adwaa and Baqaa road with a total length of 51 Kilometers. The standard MOT HMA 25R8A4Y was used for asphalt base course in this project. 25R6A4Y is the MOT Superpave mix code (25 = mix nominal aggregate size, R6 = Hail Region code, A = PG64-10, 4 = design ESAL < 30 millions, and Y = 25% or more of paved layer is located within 100 mm from the surface). Complete design for 25R6A4Y was conducted and the design gradation is given in Table 1. Optimum binder content was 5.2%, by total HMA weight.

Table 1 25R8A4Y Design Gradation

Sieve Size-mm	37.5	25.0	19.0	12.5	9.5	4.75	2.36	1.16	0.6	0.3	0.15	0.07
% Passing	100	94.9	82.2	61.2	53.1	41.2	28.7	18.6	13.8	9.0	6.2	4.1

3. BINDER CHARACTERIZATION

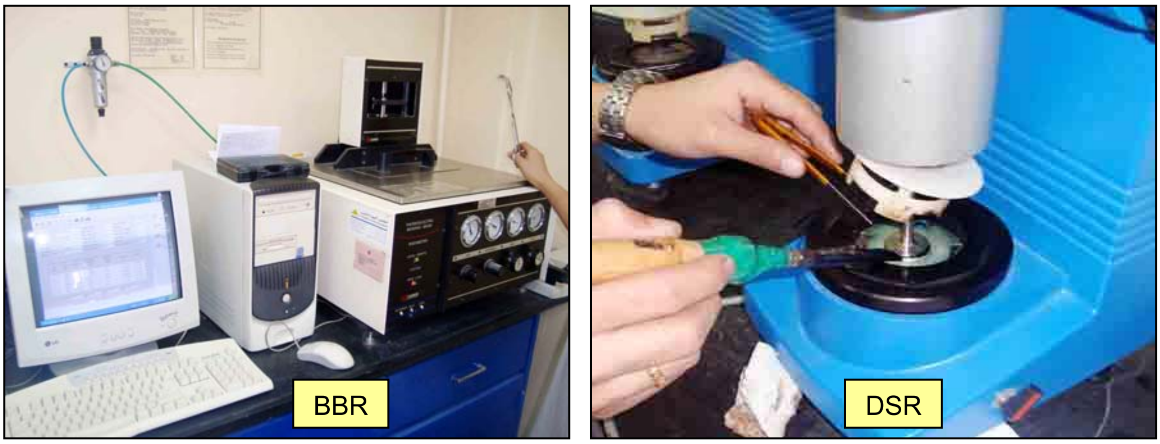
Conventional PG64-10 was blended with the three selected modifiers (SBS, Saso, and CRM) to produce modified PG70-10. SBS and CRM were obtained from Pave Guard International Enterprises in Dubai. Saso was obtained from The Saudi Company of Chemical Trading Ltd, Jeddah in the KSA. Percentages of 3, 5, and 9 (by total weight) of SBS, Saso, and CRM, respectively were blended with conventional PG64-10 to produce PG 70-10. Conventional PG64-10 and modified PG70-10 were tested using BRV, DSR, and BBR.

The BRV, DSR and BBR were used to characterize and measure the rheological properties of used binders at high, intermediate, and low temperatures. The BRV test was conducted following the AASHTO standard T-316. The DSR testing (AASHTO T-315) was done on unaged binders, as well as the Rolling Thin Film Oven (RTFO), AASHTO T-240, and the Pressure Aging vessel (PAV), AASHTO R-28, conditioned binders. BBR testing was done on RTFO and PAV conditioned binders. The RTFO test simulates the asphalt binder aging (short-term) during the manufacture and construction of HMA pavements. The PAV test simulates aging of an asphalt binder during the first 5-10 years of pavement service life. Photo 1 shows the DSR and BBR testing setups. All tests were conducted at the central laboratories of the MOT.

4. SPT SAMPLES PREPARATION

HMA mixtures were prepared at the same gradation listed in Table 1 using the conventional PG64-10 and the modified PG70-10. Mixture prepared with conventional PG64-10 was noted by “A”. Mixtures made with modified PG70-10 that was prepared using SBS, Saso, and CRM were noted by “B”, “C”, and “D”, respectively. Samples (15 cm diameter by 17 cm height) were prepared using the Superpave Gyratory Compactor (SGC). Total of 20 Superpave HMA samples were prepared for each mixture. The SPT samples (10 cm diameter by 15 cm length) were cored from those prepared plugs (Photo 2). Samples were prepared at variable air voids by adjusting the number of gyrations during compaction. Only results for HMA mixtures with 4% air voids are included herein.

Photo 1 Binder DSR and BBR Testing



Hail Region environmental data were collected and analyzed. Attention was paid to the maximum, mean and minimum monthly temperatures that affect the Superpave mixture performance. Maximum, mean and minimum monthly temperatures were 45, 21, and -6 ^{o}C, respectively. Mixtures dynamic modulus were evaluated at temperatures of -15, 0, 25, 32, and 54.4 °C and frequencies of 25, 20, 10, 5, 2, 1, 0.5, 0.2 and 0.1 Hz. Photo 3 shows dynamic modulus testing setup. Samples preparation and testing were conducted in the MOT central laboratories.

5. BINDER RESULTS AND ANALYSIS

Based on the DSR results and following the AASHTO M320-05, all modified binders were classified as PG70-10. Table 2 shows the DSR results with the specification requirements. Figure 1 shows the relationships between temperature and each of G*/sin δ (for original and RTFO samples) and G*sinδ (for PAV samples).

Photo 2 Polymers & SPT Samples Coring and Preparation

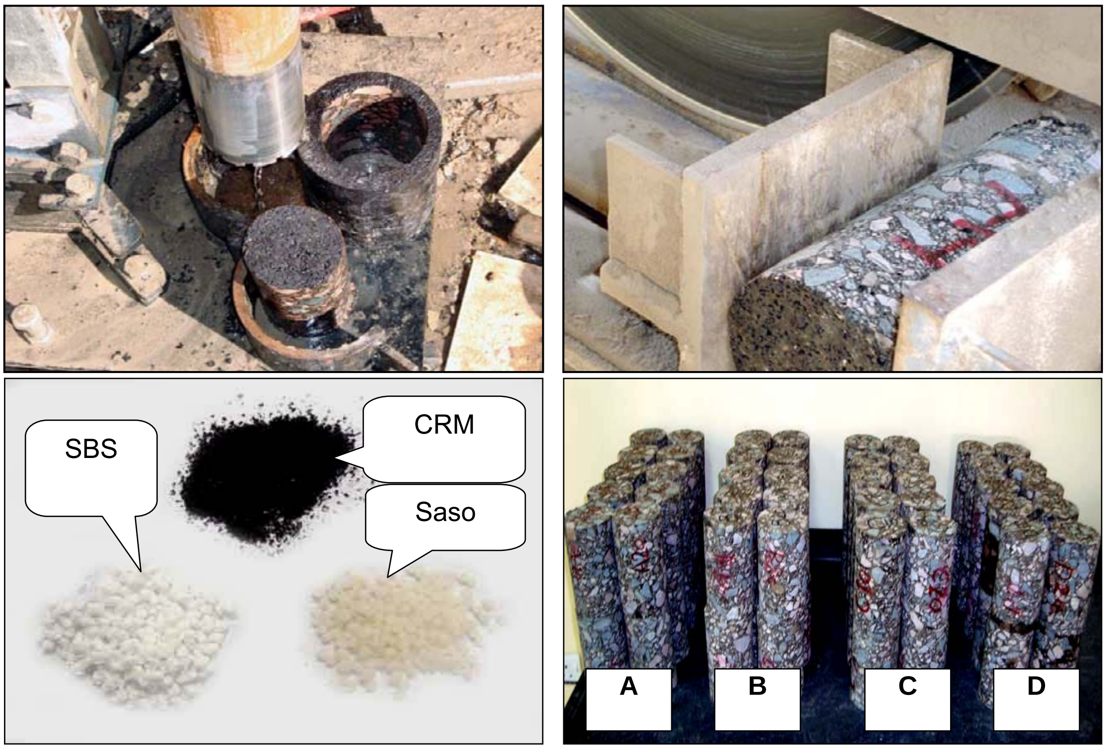


Photo 3 SPT Dynamic Testing Setup

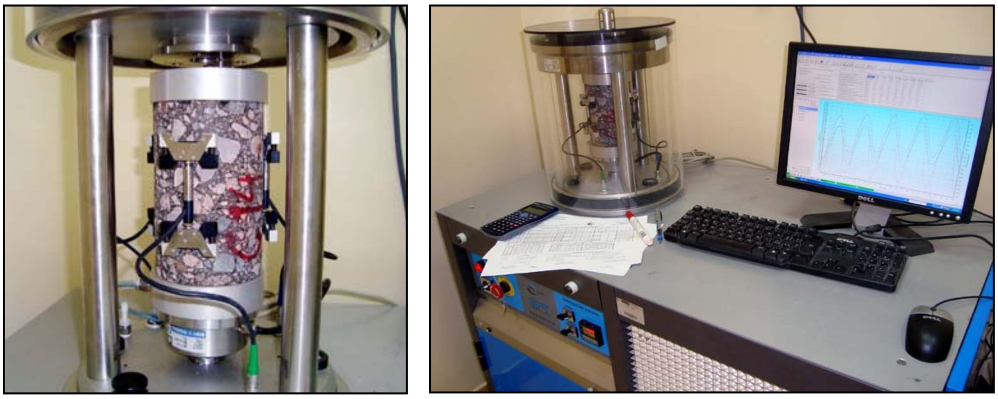
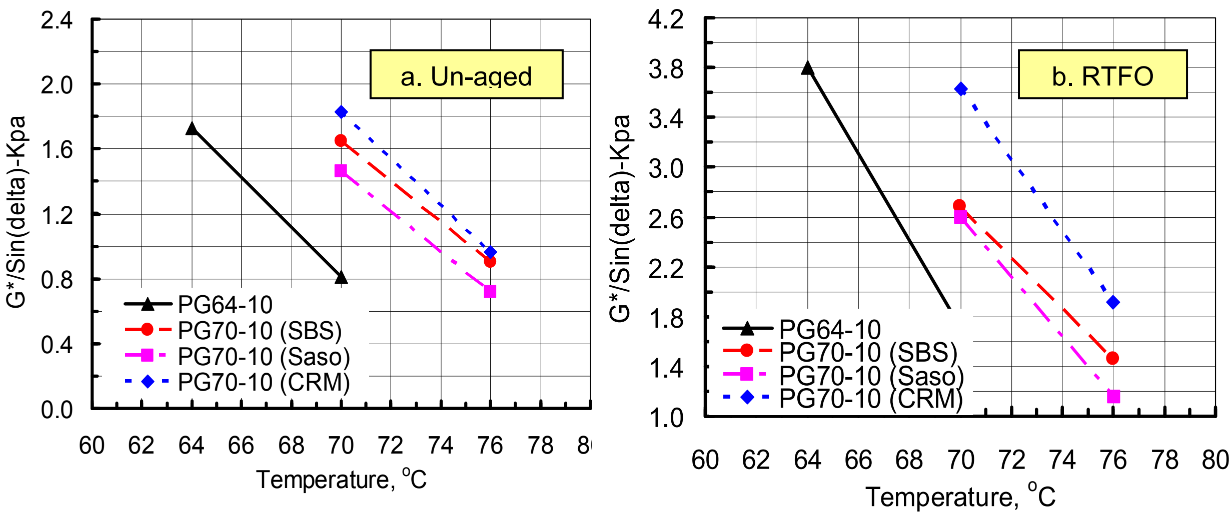


Table 2 Binder Characteristics using the DSR

Condition / Parameter		Test Results, Kpa				Requirements
		PG 64-10	PG70-10 (SBS)	PG70-10 (Saso)	PG70-10 (CRM)	
Original	G*/sinδ	1.730	1.650	1.461	1.830	Min. 1.00 Kpa
RTFO	G*/sinδ	3.799	2.686	2.597	3.628	Min. 2.20 Kpa
PAV	G* sinδ	1,750	1,750	3,500	1,750	Max. 5000 Kpa



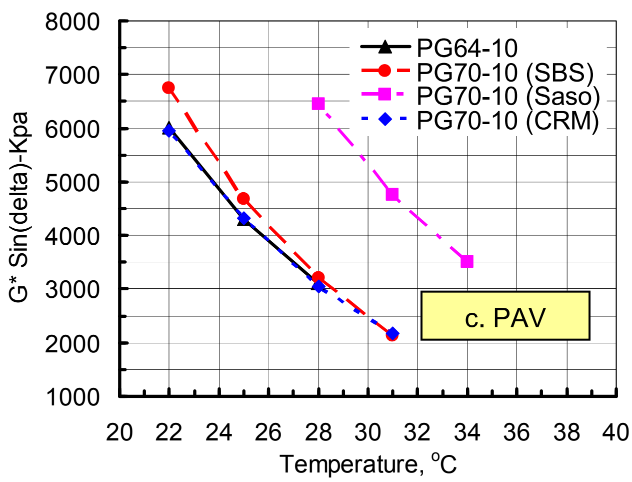


Figure 1 DSR Test Results

a. Un-aged samples
b. RTFO aged Samples
c. PAV aged samples

M-value (Table 3) proved that the minimum PG grade temperature is -10 °C except for the PG70-10 made with Saso modifier. Stiffness (S) results confirmed that the used PG binders meet the requirements in terms of lower temperature of -10 °C. Figure 2 shows the relationship between temperature and each of binder stiffness and m-value.

Table 3 Binder Characteristics using the BBR after 60 Seconds of Loading

Condition / Parameter		Test Results				Requirements
		PG 64-10	PG70-10 (SBS)	PG70-10 (Saso)	PG70-10 (CRM)	
PAV	S, Mpa	150	160	130	100	Max. 300 Mpa
PAV	m-value	0.328	0.337	0.237	0.332	Min. 0.300

6. DYNAMIC MODULUS MASTER CURVES AND RESULTS ANALYSIS

Prepared SGC plugs volumetric Properties were calculated and results showed that the air voids of cored SPT samples were lower (0.2 to 1.5 %) than those of the original SGC plugs where those cores were cut from (Figure 3). Dynamic modulus results for the Superpave HMA mixtures "A", "B", "C", and "D" were analyzed. Dynamic modulus increased as the testing temperature decreased.

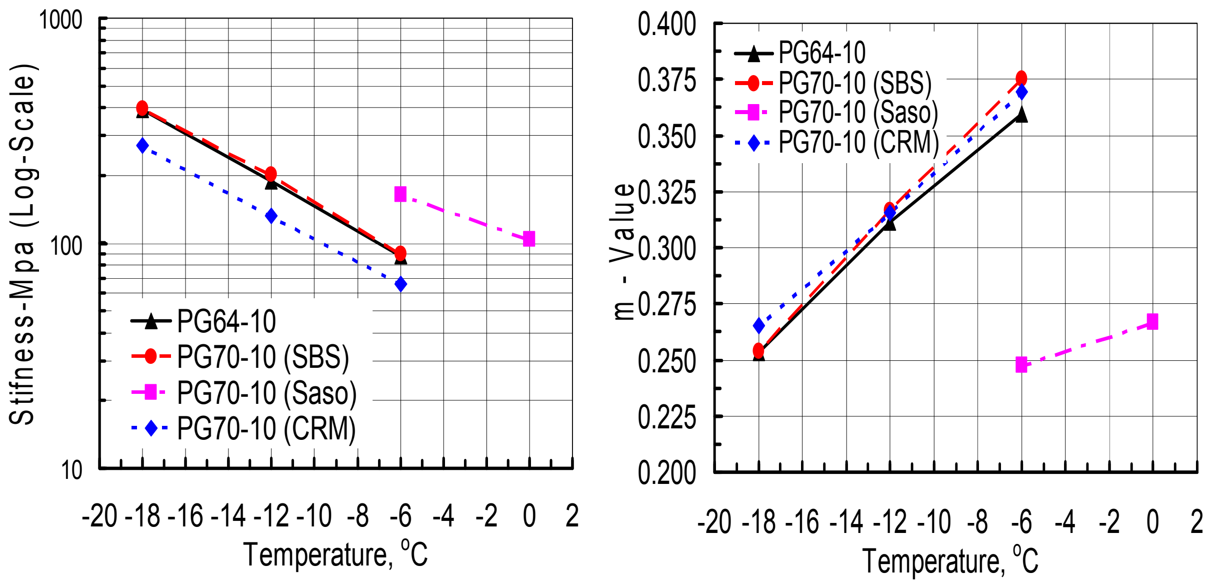


Figure 2 Temperature versus Binder Stiffness and m-Value

At the same testing temperature, dynamic modulus increased as the loading frequency increases. Phase angle decreased as the dynamic modulus increased. Also, the phase angle increased as the testing temperature increased.

Dynamic modulus master curves were developed using an Excel spread sheet to calculate the time shift factor. Master curves at reference temperatures -6, 21.1, and 45 °C for tested mixtures were developed (Figure 4). Those reference temperatures were selected based on Hail Region environment data. Using the dynamic modulus master curve equation, the dynamic modulus values have been determined at those temperatures to investigate the mixture performance using various modifiers under Hail region environmental conditions.

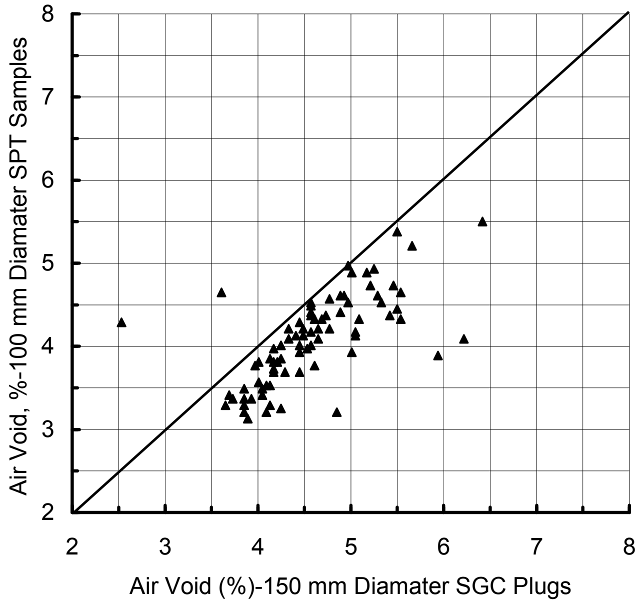
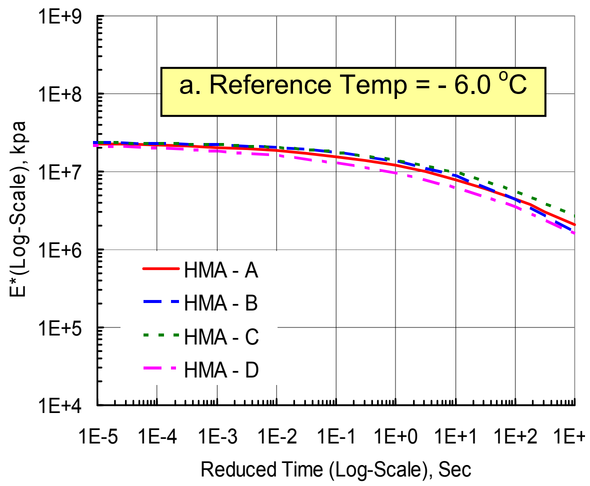


Figure 3 Air Void Content of Original SGC Plugs and SPT Cored Samples



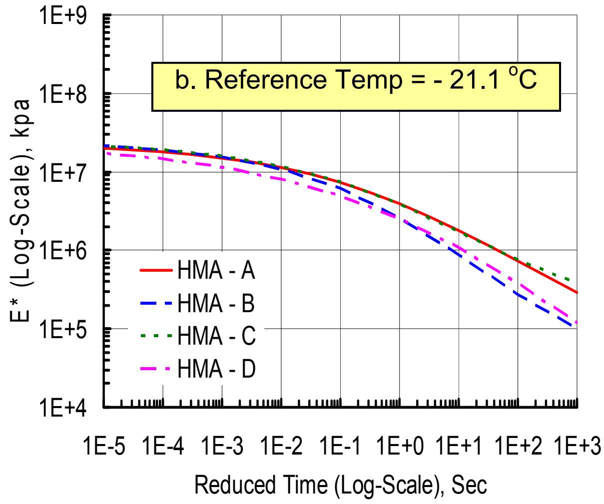


Figure 4 Dynamic Modulus Master Curves at Variable Reference Temperatures

a. Reference Temp = - 6.0 °C
b. Reference Temp = - 21.1 °C
c. Reference Temp = - 45.0 °C

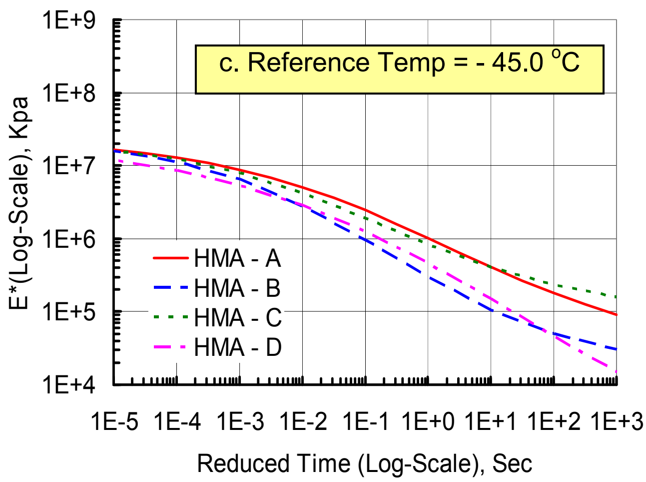


Table 3 shows the evaluated dynamic modulus at various temperature and load frequency. At reference temperature of -6 ^{o}C, mixtures “A”, “B”, “C” and “D” proved almost the same dynamic modulus values at various load frequency. In other words, no significant differences in dynamic modulus master curves were observed. As the reference temperature increased, the dynamic modulus of mixtures varied. Mixture "C" proved the same dynamic modulus as the conventional mixture "A". In other words the addition of Sasobit has no significant impact on mixture flexibility and performance. SBS and CRM modifiers improved the mixture elasticity. This improvement is more pronounced at elevated temperatures and high reduced time. As shown in Table 4, at temperature of 21.1 ^{o}C and reduced time of 0.1 second (similar almost to traffic speed of 100km/hr) the dynamic modulus for mixtures "A", "B", "C", and "D" were 1.78E+6, 8.49E+5, 1.71E+6, and 1.05E+6 Kpa, respectively. Mixture "A" and "C" proved almost the same level of dynamic modulus while mixtures "B" and "D" were more flexible and proved higher elasticity. As the temperature increased to 45 ^{o}C, the dynamic modulus of mixtures "A" and "C" remain almost the same (4.15E+5 and 3.98E+5, respectively) at the same reduced time of 0.1 seconds. Mixtures "B" and "D" proved more flexibility and the dynamic modulus were 1.05E+5 and 1.47E+5 respectively (at temperature of 45 ^{o}C and reduced time of 0.1 second). In other words the addition of SBS and the CRM enhance the elastic properties and this improvement is more pronounced at elevated temperature.

Analysis of Variance (ANOVA) was conduct to investigate the impact of both temperature and loading frequency (traffic speed) on dynamic modulus. ANOVA two factors without replications were conducted on dynamic modulus values at confidence level of 95%. Results proved that the temperature has significant effect on measured dynamic modulus. Calculated F-values were 110.6, 134.5, and 167.5 at load frequencies of 0.1, 1, and 10 Hz, respectively. Critical F-value was 3.3. Also, results proved that the polymer type has significant effect on measured dynamic modulus at higher load frequencies. Calculated F-values were 2.6, 3.6, and 5.3 at load frequencies of 0.1, 1, and 10 Hz, respectively. Critical F-value was 3.5.

Table 4 Dynamic Modulus Values Evaluated from Master Curve Equations

Temperature	Dynamic Modulus (Kpa) @ Frequency (HZ)			
^{o}C	0.1	1	10	25
HMA "A" (25R8A4Y, PG64-10)				
- 6.0	7.93E+6	1.19E+7	1.56E+7	1.69E+7
21.1	1.78E+6	3.92E+6	7.27E+6	8.82E+6
45.0	4.15E+5	1.04E+6	2.47E+6	3.37E+6
HMA "B" (25R8B4Y, PG70-10 with SBS)				
- 6.0	8.71E+6	1.35E+7	1.75E+7	1.88E+7
21.1	8.49E+5	2.55E+6	6.03E+6	7.84E+6
45.0	1.05E+5	2.95E+5	9.46E+5	1.49E+6
HMA "C" (25R8B4Y, PG70-10 with Saso)				
- 6.0	9.60E+6	1.39E+7	1.75E+7	1.87E+7
21.1	1.71E+6	3.79E+6	7.29E+6	8.97E+6
45.0	3.98E+5	8.27E+5	1.89E+6	2.61E+6
HMA "D" (25R8B4Y, PG70-10 with CRM)				
- 6.0	6.20E+6	9.50E+6	1.28E+7	1.41E+7
21.1	1.05E+6	2.49E+6	4.86E+6	6.03E+6
45.0	1.47E+5	4.59E+5	1.26E+6	1.78E+6

7. CONCLUSIONS

The MOT approved list involves various polymer types including SBS, Saso, and CRM. Those polymers were blended with conventional PG64-10 to produce modified PG70-10. BRV, DSR, and BBR were used to characterize the original, RTFO, and PAV binders. Standard MOT Superpave asphalt mixture for base course (25R6A4Y) containing various binders were tested. SPT Dynamic modulus was conducted at testing conditions similar to that of Hail Region. ANOVA was conducted to determine the impact of polymer type and testing conditions on measured dynamic modulus. At 95% degree of confidence, the polymer type has significant impact on measured dynamic modulus at high level of reduced times. The addition of SBS and CRM improved the dynamic characteristics of HMA at elevated temperatures. Conventional HMA and mixtures containing Sasobit showed similar results in terms of dynamic modulus. Other phases of this study involve the investigation of tested polymers effect on the pavement structural design and performance using the Mechanistic Empirical Pavement Design Guide (MEPDG). Also, incorporation of the SPT during the Superpave HMA design across the KSA is another future dimension of this study.

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